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HF Radio Communication Systems Design Assessment.

Contract No. DAAK80-79-C-0824

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Technical Task Report 3.3b

Sounders

HF RADIO COMMUNICATIONS SYSTEM
DESIGN ASSESSMENT
STUDY

For:

UNITED STATES ARMY

COMMUNICATIONS RESEARCH AND DEVELOPMENT COMMAND

FT. MONMOUTH, NEW JERSEY

Contract No. DAAK80-79-C-0824

30 September 1980

Prepared by:

Rockwell International Corporation

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4.2 SOUNDERS (U)

4.2.1 OVERVIEW (U)

(U) Ionospheric sounding may be divided into the two following general classes of operation:

a) true-path ionospheric sounding,
b) ionospheric parameter probing.

(U) Ionospheric sounding is used for both HF communications and for basic research purposes. True-path ionospheric sounding is used solely for HF communications, which contrasts with ionospheric parameter probing (or radar techniques) which provide a basis for ionospheric prediction besides supplementing basic research.

(U) HF communication sounding is, generally, a pre-link-establishment process for macroscopic frequency selection. True-path ionospheric sounding should be distinguished from communication channel evaluation (in-band evaluation) since in-band evaluation is a post-link-establishment process for determining the quality of a given circuit. Sounding equipment is usually separate from the communications equipment as is spectrum monitoring; however, in-band channel evaluation hardware/software may be merged within the demodulation process as discussed ~~in~~ Section 4.9.

(U) In the beginning, vertical incidence soundings were used to acquire data on which were based a frequency prediction system published in 1954 and which forms the basis of the current prediction system. Oblique soundings were first used to test and improve the predictions and understanding of ionospheric propagation. Later, oblique sounding was proposed as a real-time aid to communications ~~[1]~~.

4.2.2 TECHNICAL DISCUSSIONS (U)

4.2.2.1 Back-Scatter Sounding (U)

(U) "Back-scatter sounding" implies that the transmitter and receiver are separated by a distance that is small compared with the sounding path length, so that the transmit and receive azimuths are approximately equal. Analysis of the "back-scattered" signals is performed to determine a measure of the ionospheric structure. Back-scatter sounding may be done vertically or obliquely, though the latter requires especially large transmitter power for adequate detection of weakly reflected (oblique ground-ionosphere) signals.

(U) The two classes of back-scatter radar for determining a measure of the ionospheric structure are: conventional echo techniques or coherent backscattering, which use RF frequencies within an order of magnitude of the plasma frequencies; and the incoherent scat-

(U) tering techniques, which use high power pulses with RF frequencies much greater than the plasma frequencies present, making ionospheric reflection through the mechanism of refraction (non-tropospheric) impossible.

4.2.2.1.1 Coherent Back-Scattering (U)

4.2.2.1.1.1 Pulse Echo Vertical Incidence Sounding (VIS) (U)

(U) The original sounding methods were near vertical incidence pulse-echo techniques. They were initially concerned with obtaining the critical frequency data of the local ionosphere.

(U) Conventional vertical incidence sounding (VIS) is a pulse-echo technique to obtain real-time electron density profile data or critical frequency data of the ionosphere. A network of real-time ionospheric observations provides a better indication of the ionospheric structure and electron content than do empirical formulations which relate characteristics of geophysical activity to ionospheric parameters on a short term basis [2].

(U) VIS is a degenerate case of backscattering by which the transmitter, receiver, and monitoring device are collocated. Vertically transmitted electromagnetic pulses are "reflected" normal from the ionosphere so that records of reflected frequency versus "apparent" height (ionograms) may be generated and analyzed. The "apparent" height based on simple time delay analysis is not the same as the "true" reflection height since the group velocity of the radio wave is severely retarded while it is in the high electron density regions.

(U) Due to the presence of the geomagnetic field, the ionosphere, as a propagation medium, displays bi-refringent characteristics. The electric field components, both parallel and perpendicular to the geomagnetic field, experience differing paths. This fine structure phenomena results in the following two modes: the extraordinary mode (magnetic field perturbed), and the ordinary mode (unperturbed component). It is well known that the critical frequency of the ordinary mode is approximately equal to the plasma frequency of the reflecting* ionospheric layer. Since the plasma frequency is proportional to the square root of the electron density, analysis of ionogram data may reveal critical frequencies (ordinary modes) versus "apparent" height. Furthermore, if the antenna geometry, the magnitude and direction of the earth's magnetic field, the plasma frequencies, and the "apparent" height data are known, the electron density profile may be obtained [3]. With the aid of the fast digital computers, the density profile information can be computed in real time as the RF frequency is

*Reflection achieved through refracting gradients

(U) increased incrementally [4]. Integration of the electron density profile as a function of height will yield the local electron content which in itself is highly useful for prediction purposes.

(U) VIS is being used on a massive scale globally at middle and low latitudes to monitor temporal changes in the ionosphere associated with changes in propagation conditions that differ significantly from average conditions. The limitations imposed on the usefulness of a short-term observation network of vertical incidence sounders tend to be determined by ionospheric spatial variations and not so much by the temporal variations. Except for the very fast variations in the ionospheric structure that accompany the onset of geomagnetic storms and the passage of traveling ionospheric disturbances, hourly observations at middle and low latitudes are adequate for monitoring most temporal changes which differ significantly from average conditions [2].

(U) Numerous studies have illustrated the degree to which hourly deviations of ionospheric parameters at various locations on the globe are related. Rush [2] has tabulated foF2* correlation coefficients as a function of station separation for various times of the day and distinguished them for iso-longitudinal and iso-latitudinal paths. Results of investigations to ascertain the temporal and spatial variability of the equatorial and polar F2 regions indicate [5] both regions display a variability that is greater than that of mid-latitudes.

(U) The ionosphere is observed routinely only at certain locations on the globe and these observations must be used to determine the world-wide instantaneous behavior. Prediction of the future state of the ionosphere is greatly enhanced when observations are supplemented with any of the following:

1) Spatial and temporal regression
2) Morphological trends -- empirical algorithms
3) Non-empirical theoretical extrapolation (over season, diurnal cycle)
4) Solar activity data: sunspot number (SSN), magnetic K index
5) The neutral and ionized composition of the D, E, and F regions.

(U) Propagation Prediction:

(U) For the vertical-incidence system to be useful for short-term dynamic frequency management, at least one terminal will have to compute propagation data. There will have to be procedures for "turn-on" of the system, as sounding will not automatically be occurring between terminals. The performance monitor data, when a channel is in operation, will be compared to the predicted per-

*Critical frequency of the F2 region

(U) formance. Agreement is to be obtained within certain tolerances, and new predictions are to be made or the history file updated when the comparisons exceed these tolerances.

(U) Some current HF propagation prediction programs, such as ITS-79 "IONCAP" [72], are designed to accommodate, if available, current ionospheric data which include the individual critical frequencies and the gyro frequency. The resultant accuracy of the prediction (both the MUF* and propagation path loss) is inadequate for projecting the link quality but is helpful for macro-frequency management. Normally, the RMS path loss prediction error and the RMS MUF prediction error for large HF prediction programs (without VIS data) is 8.5 db [6] and 3.0 MHz [7], respectively. The added value of VIS data is not significant for the following reasons:

1) VIS sounding records alone provide no direct information on the density profile of the neutral constituents of the ionosphere. Path loss algorithms are highly dependent on this information. In many cases, the propagation path loss estimates are based on morphology alone unless oblique sounding is used.
2) The critical frequencies (and the circuit MUF as well) derived from vertical incidence sounding may not always represent the critical frequency of the most dominant ray (extraordinary or ordinary).
3) The spatial variability of the ionospheric structure in terms of the foF2 correlation as a function of distance is large. This reduces the validity of VIS data for medium to long link distance applications.

(U) The accuracy of a long-term statistical forecast for frequency selection is approximately as accurate as a mathematical algorithm using VIS data [8].

4.2.2.1.1.2 Linear FM Vertical Incidence Sounding (VIS) (U)

(U) In 1969, a VIS linear FM sounder system was implemented at MITRE in Bedford, Mass. The co-location of the transmitter and the receiver provides a convenient means for testing real-time correction techniques of ionospherically reflected signals.

(U) The purpose of the sounder system was not to gather data, but rather be a building block for future oblique experiments.

(U) Operationally, the first linear FM sweep in a sequence is used to measure the transfer function of the path. The computer determines the ionospheric transfer function and computes the correction to be applied by the digital control circuits to subsequent received signals [9]. Isolation between the transmitter and receiver antennas is achieved through the use of a chopping synthesizer.

*Maximum Useable Frequency

(U) Fenwick and Lomasney (1968) tested a monostatic (co-located) FM-CW vertical-incidence sounder. Due to a Faraday rotation on the propagated radio wave, a 50-60 db isolation between the transmitter and receiver antennas is achieved through orthogonal placement. The monostatic ionosonde is practical to the extent that spurious sidebands and hum components of the frequency sweep waveform can be reduced to a level significantly lower than that of the energy received after reflection from the ionosphere [10].

(U) AVCO Corporation performed a study for RADC (1972) called the HFPN Implementation Study. In this case, a single-antenna vertical incidence ionospheric sounder was assembled. The sounder consisted of a modified HP FM/CW synthesizer and breadboard models of a receiver and transmit/receive switch. The transmitter-receiver separation is achieved through a pulsed FM/CW waveform which is much different from a pulsed-CW system [11].

4.2.2.1.1.3 The Digisonde 128 (U)

(U) The Digisonde 128 is a highly complex digital sounder system which is capable of analysis of both vertical and oblique incidence ionospherically reflected wave fronts. The system is comprised of a transmitter, antenna switches, processing controller, transceiver, microcomputer, tape drive, and a digital clock. Optionally, a printer and plasma display may be used.

(U) The Digisonde 128, available since 1969, was developed at the University of Lowell Research Foundation primarily for implicit study of the magnetosphere. The coupling between the magnetosphere and the ionosphere is known to exist [12], [13].

(U) The Digisonde 128 operates in 2 modes: the ionogram mode and Doppler drift mode. The capabilities extend far beyond the classical virtual height versus frequency monitoring device. It permits storage of 5 parameter ionograms as functions of time and frequency: 1) amplitude, 2) polarization, 3) range window, 4) angle of arrival, and 5) Doppler shift. Furthermore, the curvature of the wave front can be studied.

(U) The system samples 128 pulse ranges for which the median amplitudes for 128 ranges for over at least 20 pulse returns are determined. It distinguishes vertical, non-vertical and different wave polarizations providing that the group delay time is larger than the pulse repetition period. Data compression is performed by simultaneously recording up to 16 ionograms. The "true" electron density profile is obtained in near real-time [13], [14], [15], [70].

4.2.2.1.1.4 Oblique Back-Scattering (U)

(U) Over the horizon radar (O.T.H.) or oblique back-scattering (a coherent method) in many cases is inefficient for communication

(U) [illegible] ent[illegible] [16] except when sporadic E_s propagation is possi[illegible] [illegible]8], [19]. This is because the ground reflection coeffic[illegible] (components antiparallel to the incident wave) are very small. Sporadic E_s propagation provides very strong spectral reflections from the E layer. Since 1976 the HF spectrum has been suffering from interference produced in Russia or the Ukraine. It is estimated that the transmitting power of the Russian O.T.H. radar is at least 40 MW, since it is audible in every part of the globe [20]. Concerning the Russian radar (Woodpecker), many amateur radio operators within Russia are not aware of the O.T.H. systems being used since the backscattered signals are extremely weak for detection.

(U) Monostatic backscatter sounding, whereby the transmitter and receiver are co-located, may be difficult to conduct when non-pulse waveforms are transmitted. Pulse waveforms, however, minimize the need for much isolation between the transmitter and receiver antennas. Bistatic backscatter sounding, on the other hand, provides physical isolation between the transmitter and receiver through an azimuthal deviation of the sounder receiver with respect to the oblique path line. Through the use of highly directional antennas, azimuthal symmetry can be achieved with regard to the maximum power density incident and reflection component ray paths.

(U) Backscatter sounding can be used for detecting aircraft, for example, and for deducing ionospheric parameters related to HF communications.

(U) Backscatter has the following uses for HF communications [21]:

1) To determine the skip distance and variations of it with time under the effects of various geophysical parameters which cannot be studied by other means. Also, it is for considering energy dissipation during direct propagation on radio communications and broadcast channels.
2) To monitor and forecast the operating conditions on HF radio links. Back-scatter sounding carries information about the state of the ionosphere at a distance of thousands of kilometers from the observation point in any given direction.

(U) Backscatter sounding has been used to map the foF2 within a radius of 1500 KM through a technique called "leading edge backscatter." The envelope of the skip distance or minimum time delay scatter is used to map the variation of the maximum electron density with distance [22], [23]. Dubroff, et al. (1978) showed that gradients of peak density, height and thickness can be recovered with acceptable accuracy from data [24].

(U) Europe, parts of Soviet Union, India, and the Far East are saturated with traditional instruments (sounders, transponders, etc.) for forecasting large scale ionospheric structure [24].

(U) Transponders which are simplified systems (receive and digitize only) can be located at distances of 50-500 KM from each ionosonde location on various azimuths. Transponders provide higher spatial resolution in certain regions.

(U) Based on spatial correlation studies of the foF2 and equally by knowing both the latitudinal and longitudinal electron density gradients, J. W. Wright, et al. [24] concluded that station separation of about 2500 KW in any latitude is adequate for global interpolation through the use of bistatic sounding.

(U) In 1965 R. B. Fenwick and G. H. Barry performed backscatter experiments in a manner similar to oblique tests. Granger Associates 902 step-frequency pulse equipment was used in addition to a Chirp system for comparison purposes. Pulse widths of 100 μsec and 1 msec were transmitted with average powers of 60 W and 600 W, respectively [25].

4.2.2.1.2 <u>Incoherent Back-Scattering</u> (U)

(U) The phenomena of electron-photon scattering is confirmed theoretically. Individual electrons are capable of weakly scattering electromagnetic waves. The radar scattering cross-section for an electron is very small and can be related to the classical electron cross-section. Accordingly, an extremely powerful radar system is required to detect the weak scattering as described. Demonstration of this phenomena must occur at frequencies much greater than the plasma frequencies whereby refraction can no longer be a mechanism for reflection (for ionospheric propagation). If the electron distribution in the plasma is homogeneous, the back-scattered signals would destructively interfere. This is analogous to Bragg scattering in a crystal lattice. Detection of Bragg scattering is thus possible when the reflection region has an inhomogeneous density profile. Therefore, the regions of appreciable electron density gradients in the ionosphere can be detected using a method called incoherent backscatter. Furthermore, this scattering technique can be applied to the measurement of the ion temperatures which are equal to the temperature of the neutral constituents in the same region. This information is needed for estimating the propagation path losses (i.e., non-deviate absorption loss is a function of the ion mean free paths and collision frequencies).

4.2.2.2 <u>Two-Terminal (Oblique) Sounding</u> (U)

4.2.2.2.1 <u>Step-Frequency Sounding</u> (U)

4.2.2.2.1.1 <u>Principles</u> (U)

(U) Two-terminal step-frequency sounding takes place over the actual communications path, hence it is a non-radar sounding method.

(U) Step-frequency sounding requires high power pulses to be transmitted repetitively (1-10 times) on each frequency. The high power pulses must be short in durat on so that the mode structure may be adequately resolved in time. The short pulses result in wide bandwidth utilization. Therefore, a tradeoff between the transmit power and pulse duration is necessary to maintain an adequate signal-to-noise ratio yet minimize the RF interference generated. A distinct limitation of step-frequency sounding is the time resolution available for cases in which the bandwidth utilization is greatly restricted. Often fine order multi-mode structure cannot be detected unless found with a "Chirp" sounder, which may have better than 1 μs time resolution.*

(U) Step-frequency sounding is commonly used to generate ionograms for near-real-time frequency management. When no restriction is placed on the transmitting frequencies such as to allow logarithmic spacing between 100 or more frequencies, then the received ionogram data (amplitude and propagation time delay profile as a function of frequency) allows the user to select the "apparent" near-optimum frequency.

(U) The operation of the sounder will be closed-loop, with the receiver initiating frequency changes by either waiting for a break and transmitting a code sequence back to the transmitter or else by transmitting a pilot tone back to the transmitter during full-duplex transmissions. The direct oblique sounding requires no information of terminal location, etc. and serves to check out the condition of the equipment as well. This subsystem operates at the initial "turn-on," with decisions on candidate frequencies and their quality made directly from the ionogram. Then, if necessary, dwell time on particular channels is obtained by a coded sequence transmitted on the most promising channels with quality monitors. This presumes that sounders are being repetitively operated between terminals according to some predetermined sequence in the operating plan.

(U) Reverse path sounding is accomplished when the received ionogram data is used to obtain the MUF, the usable frequency data, and the path loss data (as calculated from the received signal power and known link parameters) so that a near-optimum frequency and power level is utilized by the receiver for its transmit mode. Forward path sounding is conducted if the link information is relayed back to the transmitter for further refinement of its controllable parameters such as the frequency, data rate, and the transmitter power. The distinction between forward and reverse types of soundings is important since the HF propagation path is not reciprocal, particularly with respect to the extraordinary modes.

(U) *See Section 4.2.2.2.2

(U) The Navy Tactical Sounder System (NTSS) consists of several shore-based sounder transmitters and a number of sounder receivers. The U.S. Navy step-frequency sounder, the AN/FPT-11, is manufactured by Hermes Electronics Ltd. of Nova Scotia, Canada [73]. This 30 KW transmitter sequentially transmits a pulse on each of 80 discrete channels between 2 and 32 MHz. Each frequency transmitted consists of two pulses separated by 50 ms. Each 2.6 ms pulse is composed of a series of 13 subpulses, biphase modulated in a Barker code sequence. A Barker code pulse compression increases the effective transmitter power, retains the necessary pulse resolution, and increases the available signal-to-noise ratio by 13.1 dB [7].

(U) The AN/UPR-2 10 KHz sounder receiver, developed by NELC, sequentially processes the pulse-train input by starting the gated receiver scan at the time of the transmission. A similar receiver, the RSR 9011, is also designed to match a phase modulated Barker code with a bandwidth of 3.5 KHz.

(U) On the AN/UPR-2 receiver, a correlator operates on the binary waveform for which 30 delay-line taps provide data for the correlator on each channel. This receiver allows ionogram generation for 80 channels of interest. For the most part, it is very accurate in measuring the received signal power with overall dynamic range of 40 dB with better than $\pm\frac{1}{2}$ dB resolution [7].

(U) A step-frequency sounder is inherently too powerful for covert operation in the Army tactical and strategic environment. Though this method of oblique sounding provides near-real-time frequency management since ionogram information can be easily obtained, a great deal of risk exists for the user whose signal may be intercepted. The risk may be reduced significantly if a step-frequency sounder is limited to only one end of the link, probably at a base station, or a "safe" location. Therefore, if a step-frequency sounder for near-real-time channel evaluation must be employed, covert response based on reverse path sounding must also be used when LPI is required.

4.2.2.2.1.2 CURTS (U)

(U) One of the most complex oblique step-frequency sounding systems devised was the CURTS system (Common User Radio Transmission Sounding System). It was developed for effective real-time frequency management of the HF circuits of the U.S. Defense Communication System (DCS). The problem of frequency selection was immense due to the limited frequency allocations for each direction of each HF link of the system. The major problem for the DCS was not only to select the frequencies that would support propagation, but to minimize the effects of interference. In a three-month test, three CURTS-controlled HF trunks achieved an average of 96-percent (94-to-99-percent range) throughout for 2400-baud simulated AUTODIN traffic [26].

(U) "A test network was operated in the Pacific area with transmitters at six sites and receivers at two sites. The equipment sounded each of the 120 assigned frequencies on each of the circuits every 10 minutes. The signals were digitized and passed to a control computer where the data were compared with a time history tape and then added to that tape for use on following days at the same time. Measurements were also made of the time dispersion (multipath delay), frequency dispersion, and the background noise and interference on each of the assigned frequencies. The computer then evaluated each assigned frequency for possible interchannel interference. The computer logic also made use of ionospheric predictions and forecasts of disturbances in assessing the frequencies. A quality figure based on the binary error rate (BER) was assigned to each frequency by the computer, which then ranked the frequencies in descending order of quality figures and transmitted them via teletype to the stations to aid in frequency selection" [1].

(U) The feasibility of the CURTS system was confirmed from the test network. The system demonstrated capability of choosing the best frequencies in environments of poor propagation and high interference. It was concluded that with the CURTS system, the quality of HF (at low or medium latitudes) can be made to approach (within intended bandwidth) the reliability, availability and quality of other media such as satellites and cables [1], [26].

(U) The CURTS system was very costly. This system would be of interest to organizations having adequate financial resources that require very high reliability communications. Furthermore, it is far more than just a sounder system. It is a complete frequency management system involving real-time system trunk quality evaluation.

4.2.2.2.1.3 The CHEC System (U)

(U) The CHEC (Channel Evaluation and Calling) system was developed by CRC* to aid in maintaining good air-ground communication links. The ground station with its standard transmit-receive facilities was equipped with 2 CHEC step-frequency, ground interference receivers for measuring and encoding the ground interference levels which were transmitted from the step-frequency sounding transmitter. Air-ground synchronization was maintained by internal crystal-controlled clocks.

(U) Using reverse-path sounding, the aircraft would measure the received signal-to-noise ratio to select the "best" of 16 different frequencies observed over a period of 64 seconds for which the sounding is repeated every 2 minutes. Though this system is less complicated than the CURTS system, it provides frequency selection based on propagation and interference data in near-real-time [1, 73].

*Communications Research Centre, Ottawa, Canada

4.2.2.2.2 Swept-Frequency ("Chirp") Sounding (U)

4.2.2.2.2.1 Principles (U)

(U) Oblique chirp sounding is potentially the most covert method and requires the least transmitter power. Moreover, it is immune from the effects of fixed frequency interference and is potentially the most accurate in time-delay resolution, achieving better than 1-μs resolution. Chirp sounding, a linear FM technique, permits a transmitter to have a duty cycle of unity. If the receiver bandwidth is narrowed to a few Hertz, the frequency sweep rate may be slowed down without compromising the obtained time-delay resolution.

(U) The Barry Research Corp. AN/TRQ-35(V) Tactical Frequency Management System (TFMS) provides real-time propagation, noise, and spectrum occupancy data. The AN/TRQ-35 has three components: a sounding transmitter, sounding receiver and display, and a spectrum monitor [27].

(U) The Chirpsounder transmitter T-1373 (TCS-4B) transmits a FM-CW signal on the order of 1 watt in power, varying in frequency as a function of time while the tracking receiver sweeps in synchronization. Synchronization is accomplished if the sounding is begun within 1 second of the predesignated time; however, the receiver must either retard or advance its sweep rate temporarily in order to lock-in on the 2.5 Hz "wide" tone.

(U) The R-2081 (RCS-4B) Chirpsounder receiver reveals the relative multipath structure in real-time of the "chirp" signal by utilizing a time-compression-sweep spectral-analysis technique which accomplishes an instantaneous receiving bandwidth of 500 Hz by achieving the effect of 200, 2.5-Hz comb filters. This implies a 5 ms time delay window capability for a sweep rate of 100 KHz/sec.

(U) Collocated with the sounding receiver is a R-2093 (RSS-4) spectrum analyzer which accumulates spectrum occupancy statistics over a 30 minute period. The sounding equipment repeats operation every 5 minutes (or 15 minutes) while the spectrum monitor updates its information every 11 seconds.

(U) The sounding receiver and monitor are located at the frequency controlling end of the HF path (a form of reverse path sounding). The ionogram information displayed yields both amplitude and time delays (for modes present) as a function of frequency. Thus the user can select the best high amplitude, low multipath frequencies available. Furthermore, the spectrum monitor permits analysis of each 3-KHz segment for channel occupancy above the channel noise floor for the 30 prior minutes.

4.2.2.2.2.2 Applications (U)

(U) Speak Easy I* was intended to determine the viability of the TFMS in the naval command and control environment while meeting the following objectives [61]:

1) demonstrate compatibility of the RCS-4B Chirpsounder Receiver on a naval command and control ship in terms of installation, operation, and electromagnetic compatibility, and
2) perform reception tests using various candidate antennas aboard the U.S.S. Mt. Whitney.

(U) The RCS-4B Chirpsounder Receiver revealed no installation or operational problems. The Chirpsounder Transmitter did not need to provide more than 10 watts of power in spite of the high RF noise environment on Mt. Whitney and was shown an excellent tool for frequency management of LINK 11 network [61].

(U) Speak Easy II incorporated an RCS-4B Chirpsounder Receiver and an RSS-4 Spectrum Monitor to simulate a headquarters unit at Fort Bragg, North Carolina. Near El Paso, Texas, a TCS-4B Chirpsounder Transmitter accompanied a Special Forces unit on maneuvers. Another TCS-4B Chirpsounder Transmitter located in Sunnyvale, California, simulated a DCS entry circuit. A 65-hour test [28] was conducted to:

1) determine the degree of assistance provided by the TFMS for the Special Forces communicators,
2) compare previous ionospheric predictions with propagation predictions measured by the TFMS, and
3) show that the TFMS was compatible with Army logistics and operations procedures.

(U) The U.S. Air Force and the U.S. Army Special Forces (BR Comms. "Speak Easy II") demonstrated 100% path reliabilities for Chirpsounder predicted frequencies. It is interesting to note that long term monthly reliability charts predicted 69-85% for the frequencies utilized. It is imperative that HF propagation prediction techniques must be highly refined, i.e., utilize as much current geophysical data in semi-empirical prediction algorithms as possible, in order for them to meet the impeccable record achieved by real-time sounding (particularly chirp sounding).

(U) Teamwork/Bonded Item demonstrated for the USMC that [29]:

1) The TFMS can increase HF communications reliability.
2) The USMC personnel were adequate for operation and installation of the TFMS, and
3) the TFMS hardware was rugged enough to withstand typical USMC deployment methods and other environmental factors.

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*Military Exercise Designator

(U) HF communications reliability was excellent during Teamwork and Bonded Item with the exception of a large number of nighttime hours and few daytime hours in Teamwork, when the Chirpsounder showed no propagation [29].

(U) Solid Shield 77 was a combined-service exercise directed by the Joint Chiefs of Staff and sponsored by the Atlantic Command during May 1977. The TFMS was used directly by the Joint Task Force Command to establish the operating frequencies of major networks of the exercise. The unique measurement data presented by the TFMS permitted very rapid adjustments in operating frequency when jamming or inadvertent interference occurred [30].

(U) Trophy Dash III evaluated the feasibility of employing a spectrum sharing concept in HF communications in the tactical theater, employing the TFMS. The test was conducted using three paths, each terminating at a Net Control Station located at MacDill AFB on a 24-hour/day basis. The paths were changed continually in length and azimuth to span as many as possible tactical link types. Consequently, the frequencies were changed more than 1000 times (700 discrete frequencies) during a five day test to make maximum use of the available spectrum. The results demonstrated the high reliability achievable with this TFMS [31].

(U) Trophy Flight I established the feasibility of the TFMS. The correlation between Chirpsounder-derived estimates of communications quality and observed communications quality was very high. The interference to the chirpsounder receiver on the Tactical Deployment Control Aircraft (TDCA) was insignificant. It was found that, during this exercise, sporadic-E propagation was possible in more than one half of the 24 flight hours [32].

(U) Trophy Flight II demonstrated further capabilities of the TFMS through deployment in two actual aircraft ferrying missions -- FIFE and CRESTED CAP. The conclusions [33] about the TFMS are as follows:

1) It enables the TDCA* to maintain continuous knowledge of propagation conditions to any suitably equipped aeronautical station. Therefore, the optimum frequency (nature permits) may be used.
2) The effect of the interference on the Chirpsounder receiver caused by the TDCA HF transmitter was insignificant and vice versa.
3) The Chirpsounder receiver is easily accommodated by the TDCA.
4) A Chirpsounder transmitter power of 50 W is adequate for all high priority missions even under degraded propagation conditions.

*Tactical Defense Control Aircraft

4.2.2.2.2.3 Analysis (U)

(U) The sweep rate is defined as the rate of change of frequency with time, by the relationships,

$$\frac{\Delta f}{\Delta t} = \frac{df}{dt} = \text{sweep rate}$$

If the tracking receiver is sampling the baseband response at a frequency, f_s, the integration time, t_{int}, is computed as

$$t_{int} = \frac{N}{f_s}$$

where N is the number of samples. For an integration bandwidth, f_{int},

$$t_{int} = \frac{f_{int}}{df/dt}$$

The time resolution, τ, attainable is

$$\tau = \frac{1}{f_s}$$

Thus, $t_{int} = N\tau$.

The effects of a receiver bandwidth, B, and the sweep rate, R, ($R = df/dt$), are related as follows:

$$f_s = N \cdot 2B = 2\ f_{int} \quad \text{(2B is the effective Nyquist frequency}$$

$$t_{int} = \frac{f_{int}}{df/dt} = \frac{f_{int}}{R}\ ;\ R = \frac{df}{dt}$$

$$f_s = N \cdot 2B = 2\ t_{int}F$$

$$NB = t_{int}R$$

$$N = \frac{t_{int}R}{B}$$

Clearly, the time resolution, τ, can be expressed a number of different ways,

$$\tau = \frac{1}{2NB}$$

$$\tau = \frac{1}{2\ t_{int}R}$$

(U) The mutual dependency of N, B, R results in the following observations:

1) If the receiver bandwidth, B, is reduced, the frequency sweep rate, R, may be slowed down without compromising the obtained time delay resolution.
2) The opposite is true (of 1); i.e., large B requires large R; however, the SNR is reduced.

4.2.2.3 Operational Concepts for Sounder Applications (U)

(U) It is apparent that to fully utilize the capability of any form of ionospheric sounders, operational concepts, deployments, and procedures for sounding-based frequency-use directives must be developed. While an analysis and recommendations from frequency management considerations are treated under the Automated Frequency Management Task (3.3.g), Section 4.7, the purpose of this section is to summarize operational concepts conclusions with respect to sounders utilization specifically. The conclusions are assembled from a variety of sources, as indicated.

4.2.2.3.1 U.S. Army (U)

4.2.2.3.1.1 "Site-Survey" Discussions (U)

(U) The AN/TRQ-35 may have greatest usage as part of an overall frequency management system. There needs to be coordination between uses of the AN/TRQ-35 or other similar sounder systems [34, 35]. The use of sounders should perhaps be combined with a form of propagation prediction capabilities [36]. Some sounder-use detractors feel that the Corps area is too small for the AN/TRQ-35 application -- that its use may be counter productive. They like it more as a circuit analysis tool rather than a frequency management tool [36]. The AN/TRQ-35 chirp sounders and the "Topside" ionospheric sounders are among the current concepts that show promise in significant frequency-selection improvement. One operational concept for sounders is to install them at "gateway" terminals. However, sounders are envisioned as necessary for enhancing/augmenting propagation prediction and frequency management even within the SHORADS Air Defense C^2 area of operation [37].

(U) The "doctrine" for HF frequency management is outdated or nonexistent. Development is needed before/with the introduction of any sounders. The sounders would have to be always under "close operational control." One concept is to provide the entire TFMS (or equivalent) to the Corps level, with the sounder receiver and spectrum monitor only at the Division level. There are plans to field the AN/TRQ with a demonstration in Europe (ABSME) on automatic multichannel equipment and use it to demonstrate improvement of reliability of HF [38, 39].

(U) Concepts have been formulated for the utilization of vertical-incidence sounder measurements for refinement of NVIS propagation frequency selections and assignments. Using Digisonde 128 or equivalent V-I sounders and IONCAP or equivalent propagation prediction programs on a mini-computer, it is feasible to make refined, current-day, near-optimum selections [47, 48, 49].

4.2.2.3.1.2 Concepts and Comparisons by ECAC [44] (U)

(U) "Concept 1:

- Use of AN/TRQ-35 as tactical frequency management system
- Features: Use of multiple transmitters located with forward elements, single receiver located with unit frequency manager
- Will replace current propagation prediction methods
- Application: tactical/strategic

(U) "Concept 2:

- Use of AN/TRQ-35 as frequency selection system
- Features: Use of multiple receivers located with forward elements, single transmitter located in rear area
- Will augment current propagation prediction methods
- Application: tactical -- Corps and below

(U) "Concept 3:

- Establish world wide network of sounders to provide area service
- Features: World wide grid of transmitters, receivers with tactical units
- Will augment current propagation prediction methods
- Application: strategic/tactical/contingency situations

(U) "SIGINT/ESM Implications

Concept 1: Provides enemy with ID and locations of forward maneuver elements -- critical C+C [command and control] nodes
Concept 2: Provides enemy with ID and locations of sounders in rear areas
Concept 3: Can be used by enemy to enhance his own operations. Pre-established locations well known to enemy.

(U) "ECM Implications

Concept 1: Vulnerable to catastrophic failure modes (jamming or physical destruction)
Concept 2: Graceful degradation
Fallback to propagation predictions/prepared frequency lists
Concept 3: Graceful degradation
Fall back to propagation predictions/prepared frequency lists
Vulnerable to pre-engagement attack

(U) "EMC Implications

Concept 1: Maximum spectrum pollution
Problems with scheduling/coordinating operations

Concept 2: Spectrum pollution
Problems with scheduling/coordinating operations

Concept 3: Coordinated operations schedule
Controlled spectrum pollution"

(U) COMPARISON CHART

	"CONCEPT		
	1	2	3
SIGINT/ESM	ID/LOC of FLOD (FWD) Element of C+C network	ID/LOC of sounders in rear areas	Enemy use thru intrusion
ECM	Catastropic failure possible	Graceful degradation	Graceful degradation
EMC	Maximum spectrum pollution Schedule problems	Spectrum pollution Schedule problems	Controlled spectrum pollution
Cost	$$$	$$	$

(U) "Conclusions

- Establishment of lead agency to define requirements for sounders or other frequency adaptive techniques
- Develop O + O concepts for use
- Define best system concept/hardware configuration"

4.2.2.3.1.3 Additional ECAC Comments [46] (U)

(U) Frequency Assignment Process:

1. AFCEN (Europe) has the HF assignments list. Sixty percent are not usable, for various reasons. Many have been reassigned. Effectively "the list" has been lost. The Army policy doesn't allow "bootlegging" frequencies because they won't be available when really needed in a crisis.
2. In peace time, stick to allocation tables and use what is passed down from the Civil National Frequency Resource Agency (FRA) in the area, for instance in F.R.G. The theatre frequency manager in practice tells the Corps what frequencies to use for the next 30 days, in terms

(U) of primary and alternate frequencies for day and night and maybe frequencies for the daylight transition times.

3. There will be fewer HF nets in '85 than now. The XVIIIth Airborne Corps now has 100 HF nets. There are only 80 frequencies available for training. Requirements are for a few messages per day. Therefore the nets should share the HF frequencies. The important HF links are from the airhead back to the other side (CONUS). HF is not needed within their operational area.

   Only 20 out of the 80 frequencies are usable at any time, typically, resulting in 5 nets on each frequency operations. Should restrict use of HF to essential communication only and use other forms of communications for logistics, etc.

(U) Sounder Applications:

1. Sounders would be valuable when a pool of frequencies is available at Corps. The Battlefield Spectrum Manager has a list of frequencies for the day (the list is varied from day to day for security reasons). Based on sounder results, the manager would come up with the best frequencies from which to choose on a given day, even though the sounder results indicated the optimum frequency to use.
2. Corps: 140 km across by 200 km deep. Sound ionosphere within Corps, Qty 1. Pass the sounding results down in echelon. There should be less than 5% variation in MUF, etc., within the Corps area for these restricted distances.
3. Should have a channel within Corps which sends a continuous stream of net code numbers and frequency assignment/selection information. User to have a small digital readout of frequencies. User tunes to each in turn to find workable frequency for him. Alternatively, employ Sounder receivers at DTOC.* The Division Signal Officer will be the Battlefield Spectrum/Radiation Manager. Go through frequency selection process and pass information to Division. Division will have a division command net to pass down frequencies managed from Corps C.P. using a shared pool, at Corps level.
4. Special Forces (SF) operations (strategic) are in a "bootleg" mode anyway, since they are in a foreign country "without permission." (So they are not asking for local frequency authorization coordination.) They know the clear frequencies by observation. SF wants to use the sounder in various ways to establish an intelligent decision at the base station (BS) (friendly soil) as to what frequencies on which to make blind BC transmissions to the detachments (out stations) to tell which frequencies to use, on a scheduled basis. Thus, the base station can use sounders and spectrum monitors to make the decision as to

*Division Tactical Operations Center

(U) what frequencies are available at the base station and then disseminate that information. BS sends out messages over and over on two or three desirable frequencies. Detachment has to listen on various frequencies until it receives one to establish an order wire and decode for instructions. Uses a one-time "pad" to decode. SF path lengths: 100 km typical; 4000 km maximum; 1250 km typical maximum.

5. Rangers operate only 10-60 km behind enemy lines; are more tactical than S.F. They don't transmit until done with their mission and/or are ready for extraction. Rangers could utilize the sounder information available within (beyond) the Corps area, because of their proximity.
6. Primary net usage is emergency, short-term, quick-response role.
7. In peace time, Cemetery Net is the biggest thing in Europe. It needs a good complement of workable frequencies to use. Definite need for a sounder here. Lots of frequencies have been lost due to occupancy and new ones have not been renegotiated. Hence the European list is not as large as would appear.
8. Corps spectrum management section is to disseminate frequency assignment information 24 hours a day.

4.2.2.3.1.4 Concepts by MITRE Corp. [45] (U)

(U) "Frequency Allocation Policy

(U) To take maximum advantage of frequency adaptive techniques . . . a flexible frequency management policy is required to permit operation on the usable frequencies existing at any given time. Barry Research proposed such a plan to the Air Force which was subsequently tested and is being considered for adoption. The approach is the opposite of the current frequency allocation which assigns discrete frequencies to individual users. Since international agreement permits the armed forces the use of any frequency, except in certain bands, on a non-interference-with-other-users basis, BR has proposed to the Air Force that it identify those frequencies or bands that may not be used within the 2-30 MHz band rather than allocating a handful of permitted frequencies. This approach resulted in 70% of the HF band remaining available for use, after elimination of special frequencies and sub-bands (such as WWV frequencies, emergency, and amateur bands) that could not be interfered with. The Air Force then assumed that if no signal activity above noise threshold was detected within a given 3 kHz channel for 30 minutes, that channel was arbitrarily judged to be free.

(U) "In one test in the continental United States over 700 discrete frequencies were used with more than 1000 frequency changes, once every 30 minutes, resulting in only 2 valid interference reports. One hundred percent communications reliability was achieved. Concurrent with this test, the frequencies that would have been as-

(U) signed under normal procedures -- some 56 in this case -- were monitored for their ability to pass traffic. An average of 6 hours per day of propagation outage would have occurred per link had the link been limited to those frequencies. Moreover, only a small percentage of assigned frequencies within the propagation window were clear at any one time.

(U) "This technique for excluding specifically used frequencies, together with a basis for selecting clear channels, seems to be substantially superior to the current technique of assigning discrete frequencies. Such a policy change could possibly achieve a gain in HF performance comparable to that obtained by technological advances such as frequency agility or error correction.

(U) "A Possible Implementation

(U) To be fully effective as a theater frequency management tool, this technique would require some means to disseminate from the AN/TRQ-35 the spectrum information derived to the HF communicators in theater. This dissemination means should be secure and not subject to the HF outages it is designed to avoid, but nevertheless readily available to the highly mobile HF operator. One possible implementation is as follows. One or two sounding transmitters for determining theater propagation conditions could be located at central control locations. Net control stations (NCS) for critical HF nets could be provided with sounding receivers and spectrum monitors for direct assessment and control of HF connectivity. A central sounding receiver and monitoring facility would also operate as net control station for a secure Frequency Information Net (FIN). The NCS's of other HF nets needing frequency information would act as members of the FIN and would obtain information on frequency availability, propagation, and occupancy as needed. Secure information beacons at selected frequencies, advising of the FIN's current operating frequency, could be used for finding the FIN upon net entry. Due to the routine nature of its operations, the FIN could probably be substantially automated.

(U) "The FIN service would be nodal in character, and hence, vulnerable, but it could disseminate spectrum information to a large number of users at little cost. Its loss would not directly cause the loss of communications nets but would degrade their performance."

4.2.2.3.1.5 The Division-86 Signal Battalion O&O Concept [42] (U)

(U) This document outlines the communications means available to the Heavy Division in 1986:

(U) "The Division Commander will experience an increase in the means of communications available to him in the time frame from the present to 1986 as new equipment is fielded. The Division Command Opera-

(U) tions Net (FM) and the Division Intelligence Net (FM) will employ the Single Channel Ground and Airborne Radio System (SINCGARS) equipment. The Division Commander will be able to communicate with his major subordinate commanders over Single Channel Tactical Satellite Communications (SC TACSAT) with less restriction on distance and terrain. The Division Tactical Operation Center Single Side Band net (TOC/SSB) will utilize an improved version of the HF radio which, when used together with the AN/TRQ-35 ionospheric sounding device, will vastly improve the reliability of the HF radio net. This net has been expanded to include all major subordinate elements in the Division and it parallels the SC TACSAT net. This net will become a secure voice net through the fielding of the Advanced Narrowband Digital Voice Terminal (ANDVT) which will also permit secure data transmission. These two nets together provide the Division Commander with a resiliency in command communications that is not in the field today."

(U) "The Division C-E Officer Section includes personnel and equipment required to support the Division C-E Officer. The section is a part of the Division C-E Office and provides the detailed planning necessary for preparation and maintenance of the C-E portion of the Division SOP. The section is responsible for providing C-E assistance to other Division headquarters staff elements; preparation and distribution of the Division communications-electronics operating standing instructions (CESI), communications-electronics operating instructions (CEOI), and the Division telephone directory. The C-E Section controls the allocation of radio frequencies, provides radio frequency management for the Division and operates the CSPE.* The CSPE will be a manual function until the introduction of an automated CSPE in the late 1980's."

(U) "The AN/TRQ-35(V) Tactical Frequency Management System consists of various combinations of three equipment items. Two of these items, the Chirpsounder transmitter and Chirpsounder receiver, provide an ionospheric "test set" measuring the propagation of an HF signal vs frequency. The Chirpsounder systems reveal which frequencies will propagate, all modes of proagation (surface wave or skywave), the optimum frequency band for operation, and the extent of distortion-causing multipatch propagation. The third item, the Spectrum Analyzer, provides the extent of interference measured in 3 KHz steps across the entire 2-30 MHz spectrum during the past 5-30 minutes. The best propagating assigned frequencies can be quickly checked to find which ones are also clear of interference. Thus, the AN/TRQ-35(V) is a fully flexible system for revealing <u>all</u> of the information required to properly manage an HF circuit or network. The system operates as an independent circuit test set and is equally effective regardless of the level of sophistication of the communications equipment employed and the flexibility or changes of assigned frequencies. By providing an accurate, real-time

*Communications Systems Planning Element

(U) measurement of propagation and spectrum occupancy, the TFMS eliminates the uncertainties that hamper reliable HF operation and permits rapid isolation of probable cause for any operating difficulties. The TFMS concept is to deploy a Chirpsounder receiver and Spectrum Analyzer at the Corps Sig Bde CCEO* location and utilize up to three Chirpsounder receivers between Corps HQ location and outlying Divisions. The receiver at the Division will normally be located in the ADCEO** van."

4.2.2.3.1.6 <u>Operational Concept for Improved HF Radio</u>† [43] (U)

(U) The operational concept does not include reference to an ionospheric sounder system, per se. Instead, the concept's principal types of equipment includes Automatic Link Establishment Equipment of the following functional description:

(U) "[OHFR]† will provide short and long range communications over rugged terrain by using ground wave and sky wave propagation. The Automatic Link Establishment (ALE) and frequency hopping features of the medium/high power configurations will greatly enhance the capability of this equipment to insure maximum communications availability. The ALE consists of three components:

1) Selective calling in which calls to members of the net may be made on a discrete basis or to the entire net on an automatic basis. This assures audio muting of non-relevant communications activity, provides for a positive indication of a call received and reduces the chances of a missed call.
2) Preset frequency scanning in which a microprocessor controls the scanning of a set number of preset frequencies.
3) Automatic frequency selection in which the microprocessor utilizes the selective calling data signal as a sounding

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*Corps Communications-Electronics Officer

**Assistant Division Communications-Electronics Officer

†The document referenced [43] was based on capabilities originally planned for the Improved HF Radio (IHFR). Subsequently, the planned deployment of the features described here was revised to be in the objective HR Radio (OHFR) [74]. The text quotation has been changed to reflect the revision.

(U) signal for a Link Quality Analysis (LQA) factor. This LQA factor is stored in a matrix to automatically determine the optimum transmission frequency. ALE allows the user to simply select the address of the called station and key the system; at that time the system will determine the best preset channel from the LQA matrix, determine the availability of the selected channel, transmit the selective calling address, receive an automatic link confirmation and signal the user to begin communications. The combined features of the ALE option will provide more flexibility to the users of the assigned nets. The DTOC* net for example, which at first glance appears to have far too many users to be effectively controlled by the net control station, will be easily controlled. The normal NCS functions, as they are now known, will not be required on these nets. With the ALE modem which will be used on this and other selected nets, it will not be necessary for a net subscriber to ask an NCS for permission to transmit. Any subscriber can call another subscriber or the base station using the discrete station selective calling feature without disturbing any other subscriber in the net. Using the medium/high power adaptive configuration with 10 frequencies assigned to the net and programmed into the LQA matrix will allow any of the net subscribers to converse with any other net subscriber on any of the 10 programmed frequencies without interference to the other net users, or the base (or any other selected station) can call all subscribers on a common frequency if desired."

4.2.2.3.1.7 INTACS Update Concepts [41] (U)

(U) "Field operational capabilities for frequency and CEOI management are basically manual, slow, non-responsive to dynamic needs -- particularly in EW environment. . . . Automated capability to analyze frequency requirements, and to assign frequencies on a dynamic basis, is needed now."

(U) High Frequency Radio Operational Requirements (Sounders):

General:

(U) "An improved HF spectrum management tool will be used to support the IHF radio structure needed that will meet a significant portion of the Army tactical medium and long range single channel communications requirements in the post 1980 time frame. This improved capability will be provided by the AN/TRQ-35, Chirpsounder. This device will be deployed in the Theater and Corps areas to support the frequency allocation process within the HF band. Frequency

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(U) managers at the respective echelon will operate the equipment. The device will provide the following results:

1) Ensures HF operation based on real time measured conditions (propagation and frequency occupation).
2) Permits frequency change before circuit degrades, assisting in rapid changeover.
3) Eliminates unnecessary frequency changes.
4) Separates equipment and propagation problems.
5) Identifies broadband jamming.

(U) These capabilities will result in a HF system reliability significantly increased by real time engineering and management."

(U) Background:

1) ". . . In order to eliminate or minimize HF ionospheric propagation problems, the ionospheric sounding system must have the flexibility to support one (1) HF system/net, or be employed in a pattern to support a geographical area i.e. Corps/Theater providing all of the information required to properly manage an HF circuit or network. The AN/TRQ-35(V) eliminates many of the uncertainties that hamper reliable HF operation and permits rapid isolation of probable cause for any operating difficulties by displaying an accurate, real time measurement of propagation and spectrum occupancy.
2) The requirement for this equipment is to improve frequency management for HF communications systems throughout the tactical Army communications arena. Improved frequency management will result in more effective and efficient use of the HF spectrum, and proper frequency assignments will produce more reliable HF communications with improved grade of service.
3) Present-day HF spectrum allocation is accomplished by subdividing a number of HF frequencies allocated to a major command, reallocating and resubdividing, down to the lowest subordinate command. This results in a significant reduction of the number of frequencies available to assignment at each command level. Proper employment and use of the ionospheric sounder will provide for the discontinuance of this allocation procedure and make possible a flexible procedure making all frequencies allocated to a major command available for assignment throughout the major command and all subordinate commands on a near real-time basis.
4) Present-day HF frequency assignments to a HF system/net is based on ionospheric HF supportability predictions derived from information collected from studies of ionospheric behavior over past years. Lead time for requesting these predictions is quite extensive and are generally limited to single link -- not area coverage -- missions. The process contains variables; changing on

(U) diurnal, seasonal, yearly, and eleven year cycles. The procedure is manual, time-consuming, and yields marginal results. When system/net propagation fails, it cannot be readily determined if the failure is due to equipment/operator trouble or the absence of supporting atmospheric conditions.

5) The AN/TRQ-35 consists of the following components:

Transmitter	T-1373/TRQ-35(V)
Receiver/Monitor	R-2081/TRQ-35(V)
Spectrum Monitor	R-2093/TRQ-35(V)"

(U) The Operational Concept:

(U) "Receivers and monitors will be located at the CSPE/CSCE complex at both division and Corps level. This places the HF management tool with the frequency manager. The equipment will be installed, operated, and maintained by the staff elements responsible for frequency management. Transmitters will be engineered within the Corps communications architecture so that short, medium, and long range HF links can be simulated for division and Corps receiver/monitor elements.

(U) Transmitters will be deployed in the Corps area, rear of the division area. Transmitter sites are conceived to be co-located with a Corps area signal node. Divisions deployed separate from a Corps must receive transmitters equipment from the Corps assets. Corps authorizations proposed in this . . . [rest of sentence not readable in contractor's copy].

(U) Equipment and propagation characteristics enable the transmitters to cover a large area without placement at specific user locations. The Corps management element is the key to the entire functional area. Radio frequencies received from theater command for the Corps will be distributed to the user echelon based on commander's guidance as to the priority of the net. This is a very important SOP function within each unit. Priorities will be flexible enough to meet each situation, action or mission. This "pool" of frequencies will then be applied to the propagation statistics displayed by the AN/TRQ-35. The number of frequencies available for use then are those allocated and propagating at that given time. The frequency manager must apply the user needs to the final decision so that groundwave, NVIS, and skywave can be exploited. Data users will require special attention due to the multipath characteristic of HF. The system will greatly increase communication supportability by making maximum use of Sporadic E propagation periods during the day. This ability is not predictable with the current software package available through USACEEIA and ECAC. These general capabilities and functional requirements are essentially the same for both Corps and Division. The major difference is that it is a primary mission for Corps and an emergency capability for Division to operate when links to the Corps are disrupted.

(U) "Distribution of the frequency assignments to the Division level is essential to the concept. This information can be distributed via command/operations links on TACSAT, FM/HF and wire lines. Future distribution should include a format message on the Corps and Division Executive Command and Control System (ECS2). The distribution from Corps should be of either individual or block frequency listings. Divisional listings should be block listing with augmentation of individual for Corps type HF links or interconnections with adjacent US/NATO forces. The Division CSPE/CSCE can then distribute to the divisional users respective HF frequencies on established command/operations links. Corps CSCE elements will distribute frequency listings as required to other next lower headquarters within the Corps area for further distribution to the eventual user.

(U) "For a transition period until the entire frequency management system is reviewed/revised, the current procedure to distribute preprinted HF CEOI items should continue to provide the lower echelon user the ability to fall back to a frequency if the distribution of near real time changes is disrupted.

(U) "The AN/TRQ-35 can support single HF nets/links if so required. The Separate Brigade or contingency operations will most often find this to its advantage. The transmitters must be engineered into position with its maneuver units so that link propagation data can be accommodated. The Separate Brigade can be connected with Corps transmitters if in support of a Corps operation, precluding the installation of its own transmitters. This may be a greater advantage due to the fluid battlefield situation with its battalion elements. During Corps operations, the Separate Bde will be receiving frequency allocations as any other element within the Corps area or from supporting Division CSCE. Distinct advantages of the sounding system evolves around nuclear activity and jamming periods. Propagation and channel clarity can be determined during these periods so that the frequency manager can select supportable frequencies when he otherwise would be totally incapable of doing during these situations. Severe nuclear or jamming activity also points to the need for the division to have a capability of selecting supportable frequencies. The division can never be constrained to total dependency on the Corps for frequency allocation due to so many situations that may arise that totally degrade the communications network."

(U) "Doctrinal Deployment:

(U)

BASIS OF ISSUE ACTIVE DUTY & RESERVE	EQUIPMENT T-1373	 R-2081	 R-2093
1) Corps (Hvy & Lt)	4	2	2
a) Receiver/monitor - Corps C-E Section Corps Sig Bde TOE 11-402			

(U) BASIS OF ISSUE ACTIVE DUTY & RESERVE	Equipment T-1373	R-2081	R-2093
b) Transmitters - Corps Area Sig Bn 11-415			
c) Option: All assets within Cmd Radio Bn and task organized to Corps Area Bn and Corps C-E Section			
2) Division Receiver/monitor - Div Sig Bn, HHC-TOE 11-036 to support CSPE (ADCEO)	0	1	1
3) Separate Brigade Receiver/monitor/transmitter - Organic Signal Company a platoon with transmitters tasked to outstations assigned to maneuver units."	3	1	1

4.2.2.3.1.8 Concepts for Europe (U)

(U) (These concepts were documented by BR Communications, Barry Research Corp. [40].)

(U) "HF communications by the Army in Europe fall into four categories: international nets, short-range ground-to-ground tactical nets, nap-of-earth (NOE) comm to scout and attack helicopters, and Defense Communications System (DCS) entry. An analysis of the communication requirements of each category suggest that all spectrum management needs can be met by employing 25 Chirpsounder transmitters (of which about one-third would be operating continuously), 46 Chirpsounder receivers, and 29 Spectrum Monitors, plus spares. This equipment, in addition to modern radios and special operating procedures suggested in this report, can ensure the maximum reliability possible under either the stressed wartime environment or peacetime conditions."

(U) Chirpsounder Transmitters

(U) "Placement of Chirpsounder transmitters requires careful consideration of potential wartime requirements. These requirements can be divided into the four groups described . . . [above]. Table 4.2.2-1 summarizes the Chirpsounder transmitter placement inherent with each group. The following discussion expands the summary in the table."

(U) International Nets

(U) "Analysis of the requirement for the various international nets suggests that placement of Chirpsounder transmitters at or near the following locations will satisfy the criteria given in Table 4.2.2-1.

Bann, FRG
Barnstorf, FRG

(U) *Bonn, FRG
*Bremerhaven, FRG
Brussels, Belgium
Caknakli, Turkey
*Edingen, FRG
Elevis, Greece
*Incirlik, Turkey
Naples, Italy
*Nellingen, FRG
*Perivolaki, Greece
Verona, Italy
*Vicenzia, Italy
Werl, FRG

(U) "The asterisks (*) on the list . . . identify primary transmitter locations. These locations represent a minimum essential requirement to provide basic propagation data for communications within Germany and from German net control stations to key areas in Belgium, Netherlands, Italy, Greece, and Turkey. The other locations represent secondary backup transmitters that could be activated if any of the primary transmitters were not operating properly.

(U) Table 4.2.2-1
Chirpsounder Transmitter Placement Criteria (U)

HF Application	Chirpsounder Transmitter Placement
International Nets	• One transmitter at or near each key relay control station • One transmitter within approximate 200 km circle surrounding net subscribers
Corps Area	• One transmitter approximately centered within Corps area • One transmitter as backup placed anywhere within Corps area
NOE Communications	Can utilize Corps area transmitters
DCS Entry	One transmitter at each DCS entry location

(U) "Chirpsounder transmitters complete their sweeps in four minutes forty seconds. Because all Chirpsounder operations are divided into five minute increments, all transmitter signals to a given Chirpsounder receiver should be timed to start within any 20-second wide window. This problem becomes quite complex for an international net situation where one Chirpsounder transmitter

(U) signal may be received by more than one Chirpsounder receiver or where a single receiver may want total flexibility in selecting Chirpsounder transmitters. Thus, for the Army's international net situation, it would be desirable to have the sweep start times of all of the 15 transmitters listed above within one 20-second window.

(U) "Fortunately, normal Chirpsounder operations make this possible while minimizing the danger of mistakenly synchronizing a receiver to the wrong transmitter. There are three parameters that can be adjusted.

- Start time within the 20-second window
- Transmit times within the hour
- Sweep rate

(U) "If it is assumed that at least one Germany transmitter and all transmitters outside Germany must sweep from 2 to 30 MHz (100 kHz/sec) and that 2-16 MHz sweeps (50 kHz/sec) are sufficient for all other transmitters inside Germany most of the time, the process of sweep start time selection and sweep synchronization becomes fairly easy. Table 4.2.2-2 presents a candidate configuration for a window between 3 and 22 seconds after the start of each 5-minute segment. The table lists the 15 transmitters, shows their use with four typical Army nets (designated A, B, C, D, and G), and presents a suggested start time and use scenario.

(U) "In Table 4.2.2-2, the following code applies:

P -- Primary
S -- Secondary or backup
X -- Sweep rate = 50 kHz/sec; primary; continuously utilized
XX -- Sweep rate = 100 kHz/sec; primary; continuously utilized
O -- Sweep rate = 50 kHz/sec; backup; occasionally utilized
OO -- Sweep rate = 100 kHz/sec; backup; occasionally utilized

(U) "In the scenario of Table 4.2.2-2, it is presumed that the net primary transmitters would transmit during each interval marked X or XX. Secondary transmitters would be operational and would sweep during the intervals marked O and OO. However, power output to the antenna for the secondary transmitters would be permitted only on an optional basis. Notice that, in any given 5-minute period, only 2 or 3 transmitters would be actually radiating on a sustained basis. Also, transmitter sweep start time separations would never be less than 3 seconds.

(U) Corps Area Communications

(U) "As indicated in Table 4.2.2-1, two transmitters per Corps area should be sufficient for measurement of HF propagation requirements. Within Germany, there are doctrinal Corps areas spread between the Fifth and Seventh Corps. The Chirpsounder transmitters

(U) Table 4.2.2-2 Candidate Chirpsounder Transmitter Utilization For Typical International Nets (U)

TRANSMITTER LOCATION	TYPICAL NET USE					SWEEP RATE (kHz/sec)	TRANSMITTER SWEEP START												
							Secs After Minute	Minutes After Hour, t											
	A	B	C	D	G			00	05	10	15	20	25	30	35	40	45	50	55
Bonn, FRG		S		S	S	100	t + 22		00			00			00			00	
Barnstorf, FRG	S		S			50	t + 6	0			0			0			0		
Bonn, FRG	P		P	P	P	50	t + 9		X			X			X			X	
Bremerhaven, FRG	P		P	S	P	50	t + 3	X			X			X			X		
Brussels, Bel.					S	100	t + 7			00			00			00			00
Cakmakli, Turk.		S				100	t + 4			00			00			00			00
Ed[illegible], FRG			P	S	P	50	t + 14			X			X			X			X
Elevis, Greece		S				100	t + 20	00			00			00			00		
Incirlik, Turk.		P			S	100	t + 10	XX			XX			XX			XX		
Naples, Italy					S	100	t + 16	00			00			00			00		
Hellingen, FRG	P		S	P	S	50	t + 21			X			X			X			X
Perivolaki, Gr.		P				100	t + 15		XX			XX			XX			XX	
Verona, Italy		S				100	t + 19		00			00			00			00	
Vicenza, Italy		P				100	t + 18			XX			XX			XX			XX
Heil, FRG	S		S	S		50	t + 12		0			0			0			0	

See text for meaning of letter code.

(U) used for the international nets could also be used for augmenting the Corps area requirements. However, one must assume that, in the event of war, the fixed sites for the international nets would be subjected to physical attack and should not be relied on in lieu of a highly mobile Corps Chirpsounder transmitter complement. Therefore, no more than three Chirpsounder transmitters each for the Fifth and Seventh Corps appears necessary. Two of these could be placed at Corps Area Signal Centers (CASCs) with a third consigned as a backup to the Corps Support Command (COSCOM).

(U) NOE Communications

(U) "Skywave HF communications between a base headquarters and scout or attack helicopters does not imply a requirement for Chirpsounder transmitters aboard the helicopters. Measurement of the near-vertical ionosphere can be made using a groundbased Chirpsounder transmitter anywhere within the vicinity.

(U) "The principle of ionospheric measurement is illustrated in Figure 4.2.2-1. Within any common ionospheric region (i.e., anywhere within a roughly 200 km circle) any Chirpsounder transmitter will suffice. Thus, the Corps area transmitters . . . should be sufficient for NOE comm purposes, also.

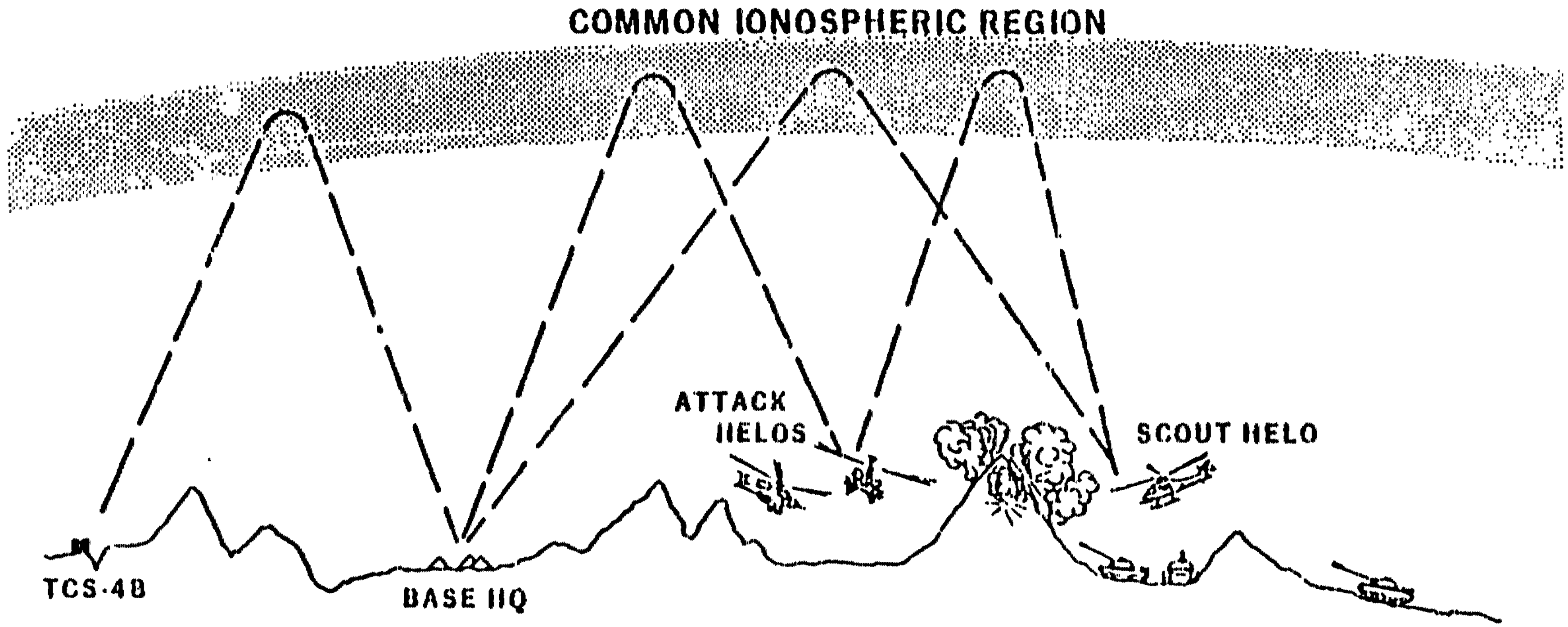
(U) DCS Entry

(U) "Obviously, propagation measurements between key DCS entry stations and Army users in Europe requires a Chirpsounder transmitter at one end or the other of the circuit. However, the number of DCS stations is small; the number of potential users is great. In addition, in a wartime scenario, some users would wish to avoid radiating a broadband Chirpsounder signal. Therefore, in the interest of minimizing Chirpsounder emissions, transmitter placement at the DCS station appears best.

(U) "Fortunately, some of the transmitters recommended for the international nets would suffice for nearby DCS entry stations. The Bann, FRG, transmitter would be close to Pirmasens. The Elevis transmitter could also do double duty. Thus, only additional transmitters for Croughton, Rota, Lajes, and any desired CONUS station would be required."

(U) CHIRPSOUNDER RECEIVERS

"Chirpsounder receivers are required at every net control station, relay control station, and any headquarters unit that will be responsible for managing HF operating assets. The following discussion describes the requirements in more detail.



- PLACE TCS-4B WELL BEHIND FRONT LINE
- MEASURE NEAR-VERTICAL PROPAGATION AND AREA-WIDE SPECTRUM OCCUPANCY AT BASE HQ
- PERFORM HF FREQUENCY SHIFTING AS APPROPRIATE WITH REAL-TIME DATA
- USABLE WITH ANY AIRBORNE NOE COMMO SYSTEM UPGRADE

(U) Figure 4.2.2-1. Principle of Ionospheric Propagation Measurement to Support NOE Communications (U)

(U) International Nets

(U) "The Army's international nets are generally structured using net control and communication relay control stations. Presently, there are plans for 25-30 of these fixed or mobile stations, both primary and alternates. Each station would be responsible for synchronizing with the appropriate Chirpsounder transmitters representing their area of concern. Table 4.2.2-2 has also been constructed to minimize any potential conflict if more than one transmitter per country is required.

(U) Corps Area Communications

(U) "The doctrinal Corps is composed of a main headquarters, a COSCOM,* and five Divisions. Numerous HF nets could, particularly in wartime, be controlled from each of these levels. Assuming a wartime requirement of at least two full Corps in Europe (and potentially three), this implies a requirement for up to 14 Chirpsounder receivers presently, with 21 units a potential requirement. In this way, each Division could control its own assets without need for any Corps-level approval or interface -- already a heavy burden in any wartime environment.

(U) NOE Communications

(U) "Operation of helicopter squadrons in a wartime scenario would be highly variable and subject to rapid change. Assuming a requirement for a helo squadron headquarters to cover approximately each 100 km of the eastern FRG border implies a need for at least seven Chirpsounder receivers.

(U) DCS Entry

(U) "Chirpsounder receivers would only be needed at DCS stations to support interstation communications. Such a requirement would not be within the Army's responsibility.

(U) SPECTRUM MONITOR

(U) "Spectrum Monitors are required at every control station where rapid determination of clear channels is vital. Such rapid determination would be needed at any station responsible for multiple nets or where intensive enemy jamming would be expected (i.e., vital HF nets and near-FEBA units).

(U) International Nets

(U) "Most of the international nets are being structured for both fixed and mobile primary and alternate control sites. Spectrum

*Corps Support Command

(U) Monitors in each of the primary sites would represent a minimum requirement. This implies a need for approximately 15 units.

(U) <u>Corps Area Communications</u>

(U) "Because of the intensity of potential jamming near the FEBA as well as a requirement for managing circuits propagating only via surface wave (where channel occupancy and transmitter radiated power are the only main parameters of concern), use of Spectrum Monitors at Corps and Division level is recommended. Placing a Spectrum Monitor with each Chirpsounder receiver under a maximum two-Corps configuration results in a potential requirement for 14 units.

(U) <u>NOE Communications</u>

(U) "The new HF radios being procured for helicopter use involve automatic scanning of a set of channels. The frequencies of these channels would be preset before each helo mission. Changes to frequency presets in flight would be discouraged. If a need for channel occupancy information would be necessary, a quick check to a nearby Corps or Division comm center with a Spectrum Monitor in place should suffice.

(U) <u>DCS Entry</u>

(U) "Because a DCS station is responsible for coordinating numerous circuits and nets, Spectrum Monitors at each site is recommended. However, provision of these units in Europe would appear to be the responsibility of the Defense Communications Agency."

(U) <u>COMM ENGINEERING NET</u>

(U) "In a Corps-level communications scenario, there may be numerous nets operating with widely scattered NCS locations. It may be impractical to place TFMS equipment at each of these NCS. In this case, a useful technique is to link all NCS with a communications engineering net. In this way, a central spectrum management station at Corps or Division headquarters can control the frequency assignments of all of its nets and can ensure that spectrum usage is based on net priority. The comm engineering NCS can advise each lower level NCS on current propagation conditions and can also advise as to appropriate bootstrap frequencies for reconstitution of their net."

(U) <u>ESTIMATED TOTAL EQUIPMENT REQUIREMENT</u>

(U) "Table 4.2.2-3 summarizes the equipment requirements described . . . [above]. In most cases, the Chirpsounder Transmitter requirement can be met with the Model TCS-4CA version. In nearly all of the international net requirements, no separate antenna would be needed. The Chirpsounder Receiver and Spectrum Monitor units would be the stock AN/TRQ-35(V) version. These would be connected (using multicouplers included in the RCS-4B) to existing tactical antennas.

(U) Table 4.2.2-3. Estimated TFMS Requirement for U.S. Army in Europe (U)

Application	Basic Equipment			War Reserve Support Kits		
	TCS	RCS	RSS	TCS	RCS	RSS
International Nets	15	25	15	7	6	6
Corps Area	6	14	14	2	4	4
NOE Communications	--	7	--	--	7	--
DCS Entry	4	--	--	--	--	--
Total Requirement	25	46	29	9	17	10

4.2.2.3.2 U.S. Navy/USMC (U)

(U) The USMC ROC [50] is the same as the USAF ROC for the AN/TRQ-35.

(U) There is renewed activity in the U.S. Navy regarding sounder applications and types [46, 69]. Conclusions on Navy operational concepts at this point by the contractor would be premature.

4.2.2.3.3 U.S. Air Force (U)

4.2.2.3.3.1 General (U)

(U) The Air Force operational concepts for sounders are based upon numerous successful exercises, as reported in section 4.2.3.2.2.3. It was assumed first that all frequencies were available for military use and then eliminate frequencies or bands where harmful interference was judged most likely to occur [27, 52].

4.2.2.3.3.2 TAC Concepts (U)

(U) The following points summarize the USAF-TAC operational concept [51].

(U) USAF-TAC Sounder Applications:

1) Large Scale:
   - Large (theatre) operations, multiple nets, substantial number of users, large frequency complement.
   - Example: TAC aircraft from aircraft carriers.
   - Make fairly good use of six sounder Tx "channels" (really sweep time slots), using six sounder transmitters strategically located.
   - Each BR-TFMS Receiver can handle three Tx channels, so need two TFMS Receivers.
   - Employ one RSS-4 Spectrum Monitor.
   - This ensemble of six Tx's, two Rx's, one RSS is called a "SYSTEM".
   - This "SYSTEM" can manage frequencies for 12 users (nets) comfortably and help out other nets on-call.
   - There is a limit to the amount of support you can give from one system.
2) Special Services:
   - Airborne command posts, AWACS, hi-priority, early warning, etc. They are currently doing some tests with sounder equipment on board this type of aircraft.

(U) Operator Considerations:

- Extrapolation of sounder results goes beyond normal radio operator's skills. They are right out of TTY school and are taught nothing about HF radio propagation.

(U)
- It takes only 15-20 minutes to get a radio operator "up to speed" on how to use/operate the TFMS.
- It takes 2 hours (min.) to 1 day to train an operator enough on the TFMS so that he can train others.
- Recommend only delegating as much frequency management/TFMS application to an operator as he has "skills" -- makes sense.

(U) Frequency Authorization and Management Process:

- The "Pentagon"/NTIA-IRAC delegates to the Theatre frequency manager certain discrete frequency assets.
- For the theatre, 3500-4000 discrete frequencies are delegated.
- These must be shared by all the U.S. and allied services in the theatre.
- The theatre frequency manager forms a joint frequency management office of all services.
- Two months before an exercise, the frequency manager doles out the frequencies to the individual service/commands.
- Some frequencies are kept in reserve by Theatre frequency manager.
- (With the use of the sounders, practices have changed somewhat.)
- The shore net may have control over 1500 frequencies.
- Each operator has a few frequencies, but is assigned frequencies on a priority (order-of-use) basis:
  1. his own frequencies
  2. the larger "pools".
- Changes in frequency assignment are made by HF order-wire channels.
- After a new assignment is made, the previously granted frequency goes back to (TFMS) central control.
- The degree of spectrum sharing depends on the skills of the operators and frequency manager.

(U) Operational Experience:

- Trained personnel can do quite well using the TFMS tool.
- So far they have not found an Exercise/Operation too large to be handled using six SDR Tx's.
- Have managed all SOLID-SHIELD exercises since 1975 using sounders.
- Normally transmit sounder from Ft. Bragg on Pope AFB.
- The joint control group is at Camp Geiger.
- One Tx is adequate for a S.E. U.S. coastal exercise, since all path lengths are about the same and paths are within 15° in azimuth.
- Hence can apply sounding results to all links.
- Everyone in the military operates on a shared, "non-interference" basis (NIB).
- Opinion is that the "free-form" NIB operation is a good one.
- They had gone to U.S. OTP to get permission to try it in exercises/tests and it worked well -- also OTP was favorably inclined to let them try it.

(U) • Thinks they can extrapolate their operational experience to "larger-than-Theatre" use, with the objective being to determine if it's viable to work on NIB there.

(U) Operational Procedure:

- If assigned channels are very congested, operator would switch to other than assigned channels.
- Select frequency area of interest based on sounder receiver output, then go to RSS-4 to find the non-interference channels.
- In a battlefield 200-km square on the FEBA, 2 or 3 sounder transmitters, well placed, can provide the propagation information needed.
- The operators obtain the propagation/frequency change information over the nets they are using.
- They don't use a separate frequency management net.
- When there are two distinct sounder systems operating separately (e.g., one on shore and one in the rear), one link is used to join the two -- the frequency information is passed on the commander's link.
- There is a motivation to keep the HF operations (link) up, if it is known that a sounder path is working (i.e., can't use the excuse that HF is "propped out", because the sounder shows that propagation does exist currently).
- Typical exercise procedure:
    - Sounder transmitters at Langley, Scott, and Eglin AFB's.
    - Sounder receiver on board aircraft.
    - The sounder at Langley alone has been employed to keep the HF net "alive" for 11 hours.
- The MUF (and f_c) is fairly constant over the area for all point-to-point users. They get the sounder information and extrapolate to other path lengths, if necessary.
- In Excercise SOLID SHIELD '73, a broadcast message of a new propagation bulletin was scheduled every hour. However, few operators were getting the message and furthermore, frequency management was poor.
- The next SOLID SHIELD used voice communications to pass the propagation/frequency information from the net control station at the command center to the technical control centers. When this two-way communication existed, the propagation/frequency management information got through and was used.
- Also, TAC has set up some additional 3-digit-address dial-up lines to get the propagation/frequency management information to the T.C.'s. The latter passed the frequencies over their nets to the pilots prior to take off.
- The sounder Tx has a very identifiable signature, but at CORPS or AFOR headquarters the emitters can be placed 10-20 km away from the headquarter site, to minimize the risk of direction-finding follow-up action.
- AF has used sounders on links from groundwave to 4200 km length.

(U) <u>TAC Operational Experience</u>

- Several nets
- Frequency manager has a list of assigned frequencies from CINC which he wants to give support from.
- He keeps a <u>manual</u> list of the frequencies used and builds up confidence <u>in his</u> frequency management.
- Prioritizes frequencies based on Rx and RSS outputs.
- Would go to some other frequencies only if these 14 or so frequencies on his list aren't any good.
- Heaviest TAC HF traffic is 2-6 a.m., when the "fragmentation order" is passed to the ops centers, for the missions that have been worked out through the night for the planes, for aircraft sorties.
- They use 75 bps RTTY for this. Hence, it takes a long time.
- They want to upgrade to higher data rates to, say, 1200 bps.
- Need sounding or channel evaluation, especially since HF propagation usually isn't very good during pre-dawn hours, for shorter distances.
- Also, during that time, many users are forced to the low frequencies for propagation, so there is lots of congestion.
- Need to find the few interference-free frequencies to use.

4.2.3 CONCLUSIONS AND RECOMMENDATIONS (U)

4.2.3.1 <u>Sounders Capabilities</u> (U)

(U) The most accurate means for specifying propagation conditions over a given HF circuit is attained through real-time oblique path sounding, particularly chirp sounding. The incorporation of real-time propagation data with accurate spectrum interference data at a receiver provides the basis for a highly refined frequency management system. If this system is utilized and its beneficiaries are constrained to fixed-frequency operation, the system effectiveness would be at much less than the full potential of its refined capabilities. When frequency allocations are no longer a constraint, however, rapid dissemination of recommended frequencies to multiple users requires a near-continuous feedback loop of frequency data from the system. This is no longer a problem when each user maintains his own frequency management system.

(U) The adoption of common vertical incidence sounding data, geophysical and solar parameter data, and/or possibly backscatter data to enhance the accuracy of semi-empirical prediction algorithms is to be explored under item 3.3.g. This approach, conducted on an individual user level with a mini-computer, would accomplish macroscopic frequency selection. The commonality of the algorithms among multiple users when adopting specific priority procedures could minimize multiple user interference, particularly when adaptive scanning receivers are employed.

4.2.3.2 Sounders Utilization and Applications (U)

4.2.3.2.1 Current Use Summary (U)

(U) The purpose of this section is to summarize the current use of ionospheric "sounders" for military HF communications enhancement. The summary is based on a limited literature search and on several "site surveys" and visits to U.S. military installations. Results of trials and exercises evaluations are reported in 4.2.3.2.2.

4.2.3.2.1.1 U.S. Army (U)

(U) There is no current operational application of ionospheric sounders to the U.S. Army tactical HF communications known to the contractor. The CENCOMS Signal Processing Group of CORADCOM, Ft. Monmouth, N.J., is conducting experiments and data collection using a Digisonde-128 vertical incidence sounder (VIS) built by the University of Lowell. This VIS facility is located at Earle N.A.D., N.J. The soundings can be used to enhance skywave communications predictions using a NBS IONCAP (modified) program residing in a connected minicomputer [47, 49].

4.2.3.2.1.2 U.S. Navy/U.S. Marine Corps (U)

(U) The U.S. Navy has been employing the AN/UPR-2 pulse type sounder in fleet operations for over 10 years. Much of the equipment is in need of repairs, but shortage of experienced, trained maintenance personnel and spare parts hinders repair activity [51], [46], [53]. Pulse sounders were proposed in the CURTS program. The Navy conducted a test comparison between the older AN/UPR-2 30-KW pulse sounder and the Barry Research "Chirp" sounder. The decision was made to continue with pulse sounders, as a contract had been let to update them in the field. Pulse sounders are not currently employed at all of the locations where installed, because of operational problems.

4.2.3.2.1.3 U.S. Air Force (U)

(U) The U.S. Air Force has tested/evaluated chirp sounders extensively in several exercises, as reported in 4.2.3.2.2.3. Current operational use in the field is limited, but procurement and deployment is in progress [47], as described in 4.2.3.2.5.3.

4.2.3.2.1.4 Other Services/Agencies (U)

(U) The Channel Evaluation and Call (CHEC) system was developed by the Defense Research Board, Canada [1]. This system is a hybrid between an "ionospheric sounder" and a "link quality analysis" system. The British Admiralty Surface Weapons Establishment has been experimenting with a similar sounding/interference monitoring system [Cottrell, Wynne, 54], as has the Australian Defence Re-

(U) search Center [Earl, 55]. The extent of current utilization of these systems is not fully known by the contractor. Apparently, these are all experimental/evaluation models and are not in current operational use.

4.2.3.2.2 <u>Test Results Conclusions</u> (U)

4.2.3.2.2.1 <u>U.S. Army</u> (U)

(U) Speak Easy II demonstrated, in part, the advantages of employing the AN/TRQ-35(V) Frequency Management System (TFMS) for the U.S. Army Special Forces. "The TFMS was found to be fully compatible with standard Army logistics and operation methods. The TFMS also demonstrated its capability for rapid selection of alternate interference-free, well-propagating frequencies before circuit degradation occurred, elimination of unnecessary frequency changes, and improvement in potential HF circuit security through optimum frequency selection, lower power operation, and jammer avoidance" [28].

(U) With regard to improving HF nets in Europe while utilizing the AN/TRQ-35(V) TFMS, Mr. McLaughlin of BR Communications recommended that a manual scanning system be used if members of a net lose each other due to a frequency change or poor connectivity. In one instance, the Army personnel took up to two hours to change frequency due to equipment malfunction and tuning problems [56], [40].

(U) Mr. McLaughlin believes that predictive techniques are not as useful as real-time sounding where nuclear blackouts may occur in isolated areas [56].

(U) "The US Army Electronics Command is developing a system to provide tactical communicators with forecasts, in near real-time, of ionospheric conditions pertinent to HF communications. To do this, vertical incidence (VI) ionospheric data was used to predict Maximum Observed Frequencies (MOF) over a 445 km path. Vertical incidence and oblique incidence (OI) maximum observed frequency data were gathered at the terminals of the path between Fort Monmouth, New Jersey, and Camp Drum, New York. A statistical analysis of the data showed the VI data to be a poor approximation to the OI data. Further, results show that using an obliquity factor based upon the secant law applied to VI data taken at an end point failed to compensate for the observed differences between OI and VI data. An obliquity function was derived, however, which did compensate for these differences. MOF forecasts based upon the model of Ames-Egan, are given for 10, 30, 50 and 120 minutes in advance" [57].

(U) "Two ionospheric sounder terminals were assembled and ionogram data was taken in vertical and oblique incidence over a 60 km

(U) path from Fort Monmouth, New Jersey to Fort Dix, New Jersey. A statistical analysis method was developed and used to demonstrate that there was no appreciable difference between vertical incidence MOFs taken at one terminal and oblique MOFs over this 60 km path. A near real-time prediction scheme was successfully adapted to use vertical incidence data to predict MOFs for the 60 km oblique path. Data from the field test was used to compare observed and predicted MOFs for 10, 30, and 60 minutes in the future" [59], [71].

(U) "Ionospheric sounder stations were set up at Fort Monmouth, NJ and Aberdeen Proving Ground, Maryland to form the terminals of a nominal 200 km path. Data was taken at each terminal in the vertical incidence (VI) mode and between the terminals in the short-path oblique incidence (OI) mode. A statistical model, previously developed for analysis of short-path ionospheric MOF data, was used to show that there was no significant difference between the short-path OI and VI data. The VI data was used in a near real-time forecasting scheme to provide short-path OI predictions 10, 30, 60, 90, and 120 minutes in advance. Predictions were compared to observed OI data" [59].

4.2.3.2.2.2 U.S. Navy/USMC (U)

(U) Speak Easy I was used to determine the success of ship-to-shore communications using the TFMS for the U.S. Navy. The TFMS was shown highly effective for frequency management of the LINK 11 network which involved both surface and skywave communications [61].

(U) Teamwork and Bonded Item were demonstrated for the USMC. HF communications reliability was excellent during Teamwork and Bonded Item with the exception of a large number of nighttime hours and a few daytime hours in Teamwork when the Chirpsounder showed no propagation. During testing, the TFMS was shown rugged enough to withstand typical USMC deployment methods and other environmental factors. The USMC personnel were adequate for operation and installation of the TFMS [29].

4.2.3.2.2.3 U.S. Air Force (U)

(U) Trophy Dash III demonstrated in a five day test that with the TFMS, maximum use of the available spectrum is possible. This refined frequency selection resulted in more than 1000 frequency changes for continuously changing link distances and azimuths [31].

(U) During Trophy Flight I, the observed interference to the Chirpsounder receiver on the Tactical Deployment Control Aircraft was insignificant. Also, the TFMS helped determine frequencies that could be efficiently supported by sporadic E in more than half of the scheduled 24 flight hours [32], [27].

(U) Trophy Flight II demonstrated further capabilities of the TFMS through deployment in two actual aircraft ferrying missions, FIFE and CRESTED CAP. The TFMS demonstrated that the TDCA may operate under optimum propagation conditions. The effect of the interference on the Chirpsounder receiver caused by the TDCA HF transmitter was insignificant and similarly was the effect of the Chirpsounder on the TDCA HF receiver. A Chirpsounder transmitter power of 50 W is adequate for all high priority missions even under degraded propagation conditions [33].

4.2.3.2.3 Operational Analyses Conclusions (U)

(U) Limited operational analyses of sounder vulnerability and EMC have been conducted by the U.S. Department of Defense Electromagnetic Compatibility Analysis Center (ECAC) and others. The purpose of this section is to summarize the results of these analyses.

4.2.3.2.3.1 ECAC Analyses (U)

(U) An analysis was conducted by ECAC in 1979 for Hq. U.S. Army Forces Command (FORSCOM) [63]. The objectives of this project were to:

1. Assess the possible improvement in XVIII Airborne Corps HF communications showed the AN/TRQ-35 (Chirpsounder/spectrum monitor, TFMS) be procured.
2. Estimate the cost of the introduction of this system into the XVIII Airborne Corps.
3. Assess potential interference of the AN/TRQ-35 with the AN/GRC-122.

(U) Conclusions of this analysis include the following [63]:

1. "To achieve maximum benefit from the TFMS, a centralized HF frequency management concept should be developed for use on the highest priority critical communication nets."
2. "Based upon reported improvements in HF communications by the Air Force and Navy elements, it seems likely that

(U) with minimal effort critical Corps HF communications nets could be improved from the reported 50-70 percent level to a level in excess of 90 percent."

3. "A test should be performed prior to purchase which simulates the future (Army) operating conditions."
4. "A brief analysis of the potential interference to the AN/GRC-122 from the (TFMS) T-1373 was conducted." The T-1373 fundamental emission "should cause little if any noticeable degradation since it occurs a maximum of once every 5 minutes." With T-1373 and AN/GRC-122 antennas separated by 100 meters, "it is possible that a spurious emission could reduce the RATT fade margin by 35 dB . . . if the teletype circuit has less than a 35 dB fade margin, due to ionospheric conditions, each spurious emission will probably cause one or two character errors just as the fundamental emission did while it was in the receiver pass band."
5. "This cosite situation should be evaluated as part of an operational test of the system."

(U) An additional detailed vulnerability and EMC analysis of the TFMS has been conducted. The report is to be available in the near term [64]. Preliminary results of the latter analysis are as follows [46]:

1. Although the real operational concept for sounder use is not developed yet, assuming a sounder transmit location 20-30 km from the FEBA leads to a Direction Finding/Location CEP (50%) radius of 1 to 10 km.
2. Conclusions of the EMC impact on the GRC-142 RTTY analysis are:
   - The sounder (10 w) should be separated at least 11 km from a victim receiver to avoid a groundwave problem on the fundamental frequency of sounder (of course sounder can block out certain subbands, so that problem goes away). Sounder should be a minimum of 0.5 km away to avoid problem due to the spurious emissions of the sounder.
   - For skywave, the maximum distance at which a RTTY receiver will be victimized by sounder is 2100 to 2300 km.
   - The maximum number of sounders which could be employed simultaneously (time-synchronized slots) in Europe for a maximum tolerable degradation to $BER=10^{-2}$, due to sounders, is calculated to be on the order of 166 to 300.

(U) A meeting of DOD personnel was held in November, 1979 at Ft. Huachuca to present and discuss adaptive HF communications techniques and the application of ionospheric sounders. Some of the recommendations of that meeting are as follows [44]:

(U) 1. "That TRADOC be requested to direct that an O & O concept be written for the operation of the AN/TRQ-35."
2. "That DCA be requested to become involved with the long-haul use of the chirpsounder to coordinate the interservice requirements."
3. "That the ECAC investigation continue along its present line of analysis."

It was concluded by the representative for the Army Special Forces that these forces could well utilize sounder receivers, in addition to spectrum monitors, and that a recommendation to investigate the use of receivers should be given to the USA Institute for Military Assistance.

4.2.3.2.3.2 Other Analyses (U)

(U) An analysis has been conducted by NOSC of the performance measures for an automated Navy tactical sounder system [62]. The objective of this work was to examine the fundamental signal design and signal processing algorithms of the UPR-2 sounder receiver. From the results, specific algorithm recommendations were made.

(U) A review and analysis of some new developments in HF communications equipment, including ionospheric sounders, has been conducted by the MITRE Corp. for DARCOM. Conclusions in the report with regard to the AN/TRQ-35 include the following [45]:

1. "Tests have shown that only one such sounding system would be sufficient to identify propagation conditions throughout a small theater area (250x300 km) since ionospheric conditions do not normally vary much within this area."
2. "In tests with the Air Force, the PPR* charts gave overall reliabilities for various paths of from 69-85% (i.e., best possible path reliability due to predicted HF variations) for a period extending over several days. Real time sounding of the HF path using the AN/TRQ-35 permitted a 100% path reliability to be achieved over the same period. Similar results were obtained in tests with the U.S. Army Special Forces."
3. "Given the difficult terrain conditions and very congested HF spectrum in Europe, such a system could significantly enhance the performance of current Army HF equipment in use there."

(U) In a discussion with a USA Special Forces communicator, there was considerable concern about the use of automated systems that distribute frequency and circuit quality information because of spoofing possibilities [65]. This has some implications about the utility of wide-area sounding and dissemination compared with direct-circuit system sounding.

*DOD's Predicted Path Reliability

(U) A recent U.S. Department of Commerce NTIA study report recommends "system sounding" over "oblique sounding" since the latter provides the most accurate predictions because it utilizes the actual communications system, including antennas. "System sounding also requires no auxiliary equipment and does not introduce additional interference into other systems as oblique sounders do." [66]

(U) <u>F.T. Zed - F.R.G.</u> [52]:

(U) The F.T. Zed agency of the Federal Republic of Germany has reportedly conducted an interference potential analysis concerning the use of the AN/TRQ-35 sounder system in the F.R.G. and reported that the interference potential is negligible. To date, this report has not been received by the contractor to verify these findings.

4.2.3.2.4 Operational Concepts Conclusions (U)

(U) Several operational concepts for the application of ionospheric sounders, particularly "chirp" oblique-incidence sounders, are presented in detail in Section 4.2.2.3. Generally, the concepts are based upon placing a sounder transmitter at each Corps Headquarters area and placing sounder receivers and spectrum interference/occupancy monitors at the Corps and sounder receivers at Divisions. There are several variations on how the propagation and interference information and associated frequency selections are to be disseminated to the users, in any equipment placement concept.

(U) The placement and utilization of any sounder and monitor equipment is highly dependent upon the total concepts for frequency management for an operational area. Rather than draw any premature conclusions based on limited considerations, the conclusions and recommendations for sounder operational concepts are deferred to the Automated Frequency Management task of this study, S.O.W. item 3.3.g, study report section 4.7.

4.2.3.2.5 Procurement and Development Activities (U)

(U) This section summarizes some of the current sounders procurement and development activities in the U.S. Government, as known by the contractor. A January, 1980 listing of HF development activities is given in Table 4.2.3-1, which includes sounder techniques.

4.2.3.2.5.1 U.S. Army (U)

(U) A draft Army letter requirement (LR) for the AN/TRQ-35(V) Tactical Frequency Management System is being circulated for review, comment, and approval [67, 68]. To date, procurement of the TFMS on an Army-wide basis has not been contracted. (The U.S. Readiness Command is buying one or two "half" systems [51], where a "full" system consists of 6 sounder transmitters, 2 sounder receivers, and 1 spectrum monitor. The Special Forces bought one spectrum monitor [51].)

(U) According to the draft LR [67], the requirement for operational Army units plus training assets, including maintenance floats, is as follows:

Equipment	Function	Total Quantity
T-1373/TRQ-35(V)	Transmitter	46
R-2081/TRQ-35(V)	Receiver	42
R-2093/TRQ-35(V)	Spectrum Monitor	42

4.2.3.2.5.2 U.S. Navy/USMC (U)

(U) There are no known current sounder procurement and development activities within the U.S. Navy, although sounding and channel evaluation for adaptive communications are being actively studied [46, 51, 62, 69].

(U) The USMC has established a Required Operational Capability (ROC) document for sounders [50]. The USMC has set a target date of initial operational capability for FY82 [67].

4.2.3.2.5.3 U.S. Air Force (U)

(U) The U.S. Air Force has a $5.2 M contract with BR Communications, Barry Research Corp., to buy 5 "full" TFMS systems, each with 6 transmitters, 2 receivers, and 1 spectrum monitor [51].

4.2.3.2.5.4 Other (U)

(U) There are no known current procurements of sounders by allied nations [67].

(U) The U.S. Department of Commerce NOAA Space Environment Lab has developed a new general-purpose computer-based system for pulsed RF measurements of the ionosphere (sounders). This is a development of the earlier Dynasonde concept to permit full digital signal processing of returned echoes. A number of instruments are now being produced for various institutions which will form the basis of a coordinated research program over the next ten years [32].

(U) Table 4.2.3-1. Partial Listing of HF Development Activities (U)

Army

Program	Developer	Comments
1. Letter of Requirements for AN/TRQ-35 (DRAFT)	US Army Signal Center	Suggest initial Army purchase of 36 ea AN/TRQ-35 chirp sounders (=$9M). RAM is being prepared prior to LR submission to TRADOC. USACC requested 6 units for 11th Signal Brigade in addition to 2 units each for 5th Signal Command and 35th Signal Brigade.
2. Frequency Scanning Radio System	US Army Avionics R&D Command	System under development for Nap-of-Earth (NOE) helicopter comm net.
3. Radio Propagation Forecasting Device	US Army Institute for Military Assistance	Concept Evaluation Program (CEP) approved for Navy developed system, called PROPHET, with USACEEIA as independent test activity.
4. Sounder Test	5th Signal Command	Demonstration of AN/TRQ-35 on Cemetery Net with FRG observation and EMC evaluation.
5. HF Radio Improvement Program	USACC, DCSOPS	Develop concept for improvement of emergency communications for post, camp and station using adaptive techniques; also MARS program.
6. Improved HF Propagation Predictions	USACEEIA EMEO-PED	Implementation of improved propagation engineering models with direct AUTODIN access from USER to EMEO. Near real-time forecasting and post-nuclear burst analysis capability included.
7. Utilization and Impact Study of Frequency Adaptive Techniques	USACEEIA EMEO	Survey of technology to meet USACC needs for immediate improvement of HF radio.

(U) Table 4.2.3-1. Partial Listing of HF Development Activities, Continued (U)

Navy

Program	Developer	Comments
1. Frequency Scanning Adaptation of AN/PRC-104 for Marine Corps	Naval Ocean Systems Center	Components in prototype form are being tested.
2. Validation Analysis of Navy Propagation Models for HF Skywave	Naval Ocean Systems Center	Study sponsored by Navy Frequency Management Office to evaluate standard models vs MINI-MUF model using sounder data base. USACEEIA queried as to desire to have Navy validate IONCAP model at the same time ($170K)
3. PROPHET	Naval Ocean Systems Center	This stand-alone near-real-time forecasting system has interest of Army Special Forces as well as Navy. System was developed as a portion of FOTACS.
4. Fleet Operation Telecommunications Automated Control System (FOTACS)	Naval Ocean Systems Center	This is a large-scale management tool for communications status, record keeping and frequency assessment/management.

(U) Table 4.2.3-1. Partial Listing of HF Development Activities, Continued (U)

Air Force

Program	Developer	Comments
1. AN/TRQ-35 Training Material	AFCS/DOYF	To provide USAF with training documentation plus audio/visual aids for operation/maintenance of chirp sounder to include concept of use.
2. BEERCAN Messages	AFCE/DOYF	To provide 6-hour updates to long-term Frequency Reliability Tables for HF radio operators via worldwide radio broadcasts from USAF MARS stations, implementation schedule early 1980.
3. Acquisition of AN/TRQ-35 Chirp Sounders	USAF Procurement Office, Sacramento, CA	5.5 systems $4.5M; delivery in 1980.

(U) Table 4.2.3-1. Partial Listing of HF Development Activities, Continued (U)

Industry

System	Vendor	Application
Chirp Sounder (AN/TRQ-35)	BR Communications, Sunnyvale, CA	On-line channel evaluator for real-time frequency assessment, management and selection over HF radio links (approximately $250K per system; current USAF buy of 11 systems).
SELSCAN	Rockwell International, Collins	A conceptual system using selective frequency scanning and calling codes to manage and operate automatically a large HF radio net.
F2 MUF Calculator, Hand-Held	Hughes Aircraft Company	A preprogrammed calculator giving near-real-time frequency forecasts using the Navy MINI-MUF program and great circle route calculations.

4.2.3.3 Recommendations Regarding Sounders (U)

(U) Chirpsounding with spectrum monitoring is the ultimate sounding concept for truly empirical frequency management. It has demonstrated its usefulness and high capability to all sectors of the U.S. military. Though a large network of Chirp sounders can be accommodated on a non-interfering basis through time division multiplexing, global control of Chirp sounding practices does not appear feasible. Because of the large expense for an AN/TRQ-35 Tactical Frequency Management System, massive scale Chirp sounding is not expected to occur for many years. It is recommended that Chirpsounding with spectrum monitoring be used for link configurations when link connectivity is of high priority.

(U) There is great need for semi-empirical HF prediction capabilities which are not polluters of the RF spectrum. They are, however, an approximate means of frequency management and offer little help in nuclear stress environments. Prediction techniques are anticipated to be further refined especially when supplemented with current geophysical/solar data and vertical incidence data. Therefore, enhanced prediction techniques should be used whenever possible to avoid generating excessive RF interference.

(U) Backscatter sounding, particularly Chirp bistatic backscattering, is a powerful means for determining oblique path MUF's and for mapping the spatial profile of the foF2's; however, it is by far the greatest RF polluter.

(U) Vertical incidence sounding does not require large transmitter powers, nor does it appear to be a large polluter of RF spectrum, in a global sense, if a large number of users benefit from each ionosonde for which predictions may be further enhanced.

(U) Step frequency oblique sounding is a powerful tool for real-time frequency management. The CURTS system demonstrated this while extending its capabilities to include refined trunk channel quality measurements. The RF power, the cost, and the complexity of the system are the main limitations.

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